# AVR064: STK502 – A Temperature Monitoring System with LCD Output

## Features

- **Presenting Data on an LCD Display**
- **Temperature Measurement**
- **Real Time Clock (RTC)**
- **UART Communication with a PC**
- **PWM Implementation**

## Introduction

The STK502 board is a top module designed to add ATmega169 support to the STK500 development board from Atmel. STK500 and STK502 provide all hardware needed to get started developing with the ATmega169. This application note is an example of how to use the ATmega169 and the STK502.

It includes:

- ATmega169 code example written in IAR EWAVR 2.27.
- Flowcharts explaining the code.
- Instruction on how to configure the STK502.
- A pre-programmed ATmega169 including the example in this application note is shipped with each STK502 kit.
- The source code is found on the “AVR Technical Library” CD shipped with the STK502. It can also be found on the Atmel web site, www.atmel.com.

8-bit AVR® Microcontroller

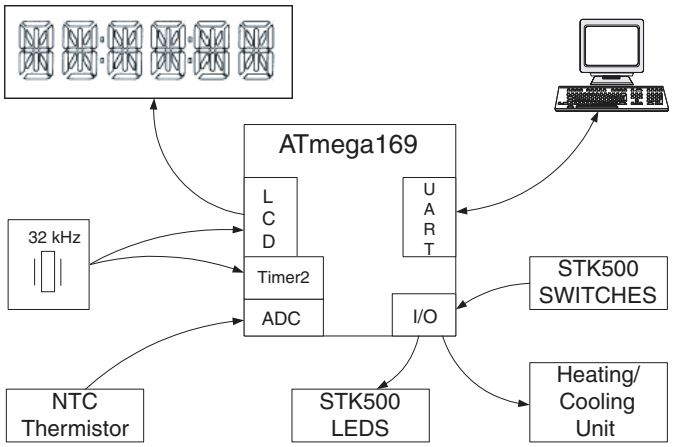
Application Note

Rev. 2529A–AVR–11/02

## Application Overview

This application note describes how to get started with the ATmega169 microcontroller (MCU), the first AVR that has a built in LCD controller/driver. This application is a temperature control application, including a Real Time Clock. It will monitor the temperature through a sensor, and regulate the temperature if a heating/cooling unit is attached.

**Figure 1.** Application Overview




The LCD starts with scrolling the text: “STK502 example application for ATmega169”. It is required that the example code is programmed into the ATmega169 and the hardware is set up according to the section “Hardware Configuration” on page 6.

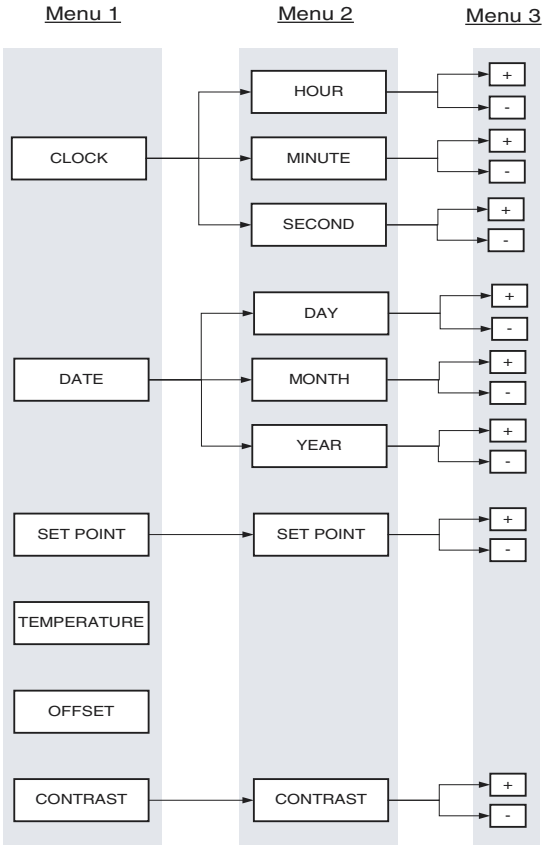
Select a desired temperature set point. When the temperature goes below this set point value, the Heater I/O pin will go high, and a LED on STK500 will flash. When the temperature goes above the set point value, the Cooler I/O pin will go high, and another LED on the STK500 will flash. The duty cycle of the LED flashing will vary with the actual temperature deviation from the set point (the greater the deviation is, the brighter the LEDs will shine) The LCD will display time and temperature information. All data that is presented on the LCD will also be sent through the UART-interface and can be received by etc a standard terminal.

Pressing a button on the STK500 will toggle the different information on the LCD. This information is:

- CLOCK: RTC running on the ATmega169
- DATE: Calculated from the RTC
- SET POINT: Selected temperature
- TEMPERATURE: Measured temperature
- OFFSET: Difference between the measured temperature and the set point
- CONTRAST: Shows all the segments available with the default hardware strapping.

Adjusting the CLOCK, DATE, SET POINT, or the CONTRAST can be done by using three of the SWITCHES on the STK500. Since these switches are used for different functions, there is a need for a menu system. See Figure 2 for an overview of how the menus are arranged in this application.

**Figure 2.** Menu System




Please see section “STK500 Switches” on page 17, for more detailed information on how to use the menu system.

The CLOCK, DATE, and SET POINT can also be adjusted from the UART interface. See section “Terminal” on page 21.

The implementation is designed to be used with the STK502 and the LCD display that is included in this starterkit. For technical specifications and the LCD bit mapping please refer to the “STK502 User Guide” and for more information on the LCD driver see application note “AVR065: LCD Driver for the STK502 LCD”.

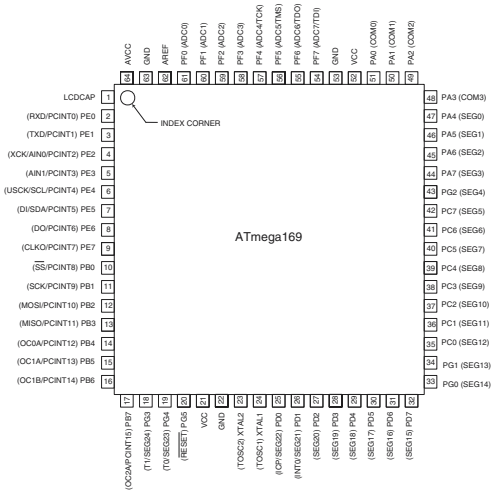
# Hardware Description

## ATmega169

ATmega169 is an ultra low power AVR 8-bit RISC microcontroller. It includes 16K byte Self-programming Flash Program memory, 1K byte SRAM, 512 byte EEPROM, and 8-channel 10-bit A/D converter, JTAG interface for On-chip Debugging and 4 X 25 Segment LCD driver. It can do up to 1 MIPS throughput at 1 MHz for ATmega169V, or 4 MIPS throughput at 4 MHz for the ATmega169L.

The ATmega169 is an excellent choice for low power applications that require user interaction (LCD + keyboard) and the possibility to interface analog sensors etc.

**Figure 3.** ATmega169



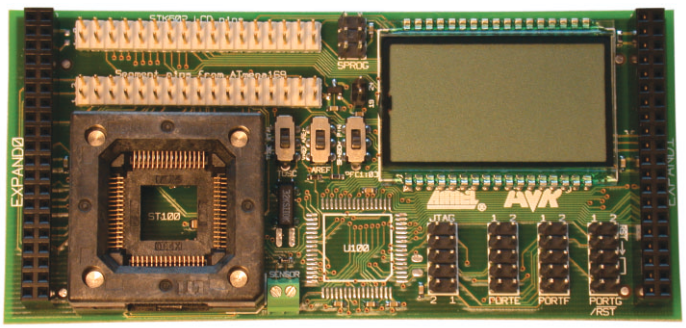

See ATmega169 data sheet for more information.

## STK502

The STK502 board is a top module designed to add ATmega169 support to the STK500 development board from Atmel.

STK502 includes connectors and hardware allowing full utilization of the new features of the ATmega169 including an LCD display, while the Zero Insertion Force (ZIF) socket allows easy use of TQFP packages for prototyping.

**Figure 4.** STK502 Top Module for STK500




See the STK502 User Guide for more information about the STK502.

### LCD Display

Liquid Crystal Displays (LCDs) are categorized as non-emissive display devices. In that respect, they do not produce any form of light like a Cathode Ray Tube (CRT). LCDs are composed of a polarized liquid crystalline material in between two plates of glass. Typically, one plate is called the common or backplane, and the other is called a segment or frontplane. In a reflective LCD panel (one that has no back light) a voltage difference applied across the two electrodes will result in a polarization which will prevent the light from reflecting back to the observer. This will appear as a dark segment and is, therefore, considered ON. A lack of voltage difference will allow the light to reflect back and is considered OFF.

For more information on the LCD driver, see application note “AVR065: LCD Driver for the STK502 LCD"

### NTC Thermistor

Various types of sensors can be used to measure temperature. One of these is the thermistor, or temperature-sensitive resistor. Most thermistors have a negative temperature coefficient (NTC), meaning the resistance goes up as temperature goes down. Of all passive temperature measurement sensors, thermistors have the highest sensitivity (resistance change per degree of temperature change). Thermistors do not have a linear temperature/resistance curve.

The NTC thermistor used with this application has a resistance of 10 kΩ at 25°C ($T_{AMB}$), beta-value of 3450 and a tolerance of ±1%. The voltage over the NTC can be found using the A/D converter in the ATmega169. See the ATmega169 data sheet for how to use the ADC. And by the use of the following equation, the temperature can be calculated.

$$\text{Temperature} = \frac{\beta}{\ln\left[\frac{V_{ADC}}{V_{REF} - V_{ADC}}\right] + \frac{\beta}{T_{AMB}}} - T_{ZERO}$$

$\beta$ = 3450

$V_{ADC}$ = Voltage calculated from the A/D conversion

$V_{REF}$ = 1.263V

$T_{ZERO}$ = 273°K

$T_{AMB}$ = 298°K (273° + 25°)

## Hardware Configuration

In order to make the example code work, it is required to set up the cables and switches in the correct order. Figure 5 and Figure 6 shows how to set up the cables and switches.

**Figure 5.** Cable Settings

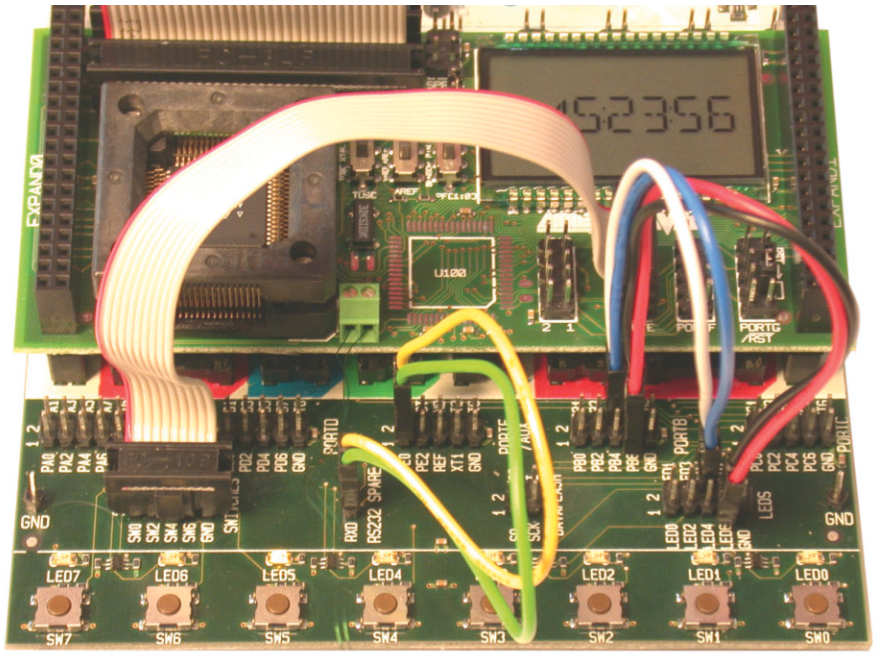
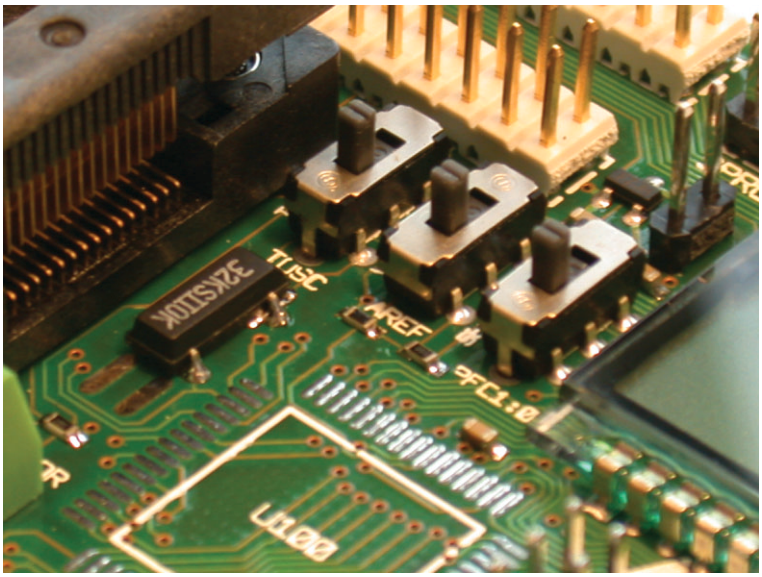



**Figure 6.** Switch Configuration

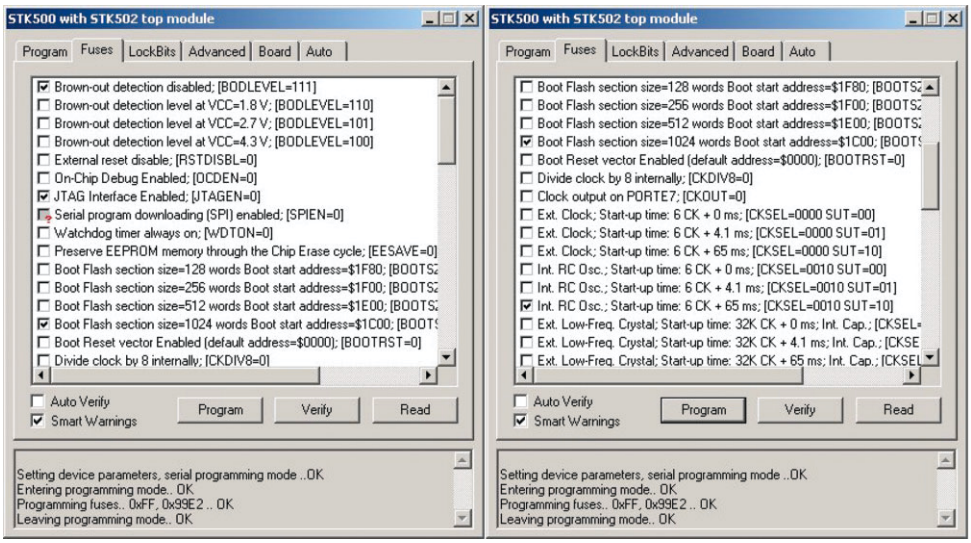



- Connect PORTE on the STK502 to the SWITCHES header on the STK500 with a 10-pin cable.
- Connect PB5/PB6 to LED5/LED6, PB4/PB7 to respectively Heating/Cooling element. If no heating/cooling element is available, just connect PORTB to the LEDs using a 10-pin cable.
- Connect PE0/PE1 on the STK500 to the RXD/TXD.

- Connect the “Segment pins from ATmega169” to the “STK502 LCD pins” with the 34-pin cable.
- Place a jumper on the 2-pin header “19 24”
- Insert the NTC thermistor in the screw terminal.
- All of the three switches on the STK502 should be in the position towards the two-screw terminal block, i.e., the TOSC switch should be in the TOSC position, the AREF switch should be in the VREF position and the PF[1:0] should be in the SENSOR position.
- Connect PG5 and $\overline{\text{RST}}$ with a jumper, on PORTG/$\overline{\text{RST}}$.

And most importantly, insert the ATmega169 in the ZIF-socket. The ATmega169 that comes with the STK502 kit, is pre-programmed with the example code. If it is required to re-program the ATmega169, see the STK502 User Guide for help on this topic. The AVR064.hex file that should be programmed into the ATmega169 can be found on the “AVR Technical Library” CD that comes with the STK502, and on the ATMEL web site, www.atmel.com. If the ATmega169 is re-programmed make sure the fuses are set up according to Figure 7.

**Figure 7.** Fuse Settings


STK500 with STK502 top module
Program
Fuses
LockBits
Advanced
Board
Auto
Brown-out detection disabled; [BODLEVEL=111]
Brown-out detection level at VCC=1.8 V; [BODLEVEL=110]
Brown-out detection level at VCC=2.7 V; [BODLEVEL=101]
Brown-out detection level at VCC=4.3 V; [BODLEVEL=100]
External reset disable; [RSTDISBL=0]
On-Chip Debug Enabled; [OCDEN=0]
JTAG Interface Enabled; [JTAGEN=0]
Serial program downloading (SPI) enabled; [SPIEN=0]
Watchdog timer always on; [WDTON=0]
Preserve EEPROM memory through the Chip Erase cycle; [EESAVE=0]
Boot Flash section size=128 words Boot start address=$1F80; [BOOTS
Boot Flash section size=256 words Boot start address=$1F00; [BOOTS
Boot Flash section size=512 words Boot start address=$1E00; [BOOTS
Boot Flash section size=1024 words Boot start address=$1C00; [BOOTS
Boot Reset vector Enabled (default address=$0000); [BOOTRST=0]
Divide clock by 8 internally; [CKDIV8=0]
Auto Verify
Smart Warnings
Program
Verify
Read
Setting device parameters, serial programming mode ..OK
Entering programming mode.. OK
Programming fuses.. 0xFF, 0x99E2 .. OK
Leaving programming mode.. OK
STK500 with STK502 top module
Program
Fuses
LockBits
Advanced
Board
Auto
Boot Flash section size=128 words Boot start address=$1F80; [BOOTS
Boot Flash section size=256 words Boot start address=$1F00; [BOOTS
Boot Flash section size=512 words Boot start address=$1E00; [BOOTS
Boot Flash section size=1024 words Boot start address=$1C00; [BOOTS
Boot Reset vector Enabled (default address=$0000); [BOOTRST=0]
Divide clock by 8 internally; [CKDIV8=0]
Clock output on PORTE7; [CKOUT=0]
Ext. Clock; Start-up time: 6 CK + 0 ms; [CKSEL=0000 SUT=00]
Ext. Clock; Start-up time: 6 CK + 4.1 ms; [CKSEL=0000 SUT=01]
Ext. Clock; Start-up time: 6 CK + 65 ms; [CKSEL=0000 SUT=10]
Int. RC Osc.; Start-up time: 6 CK + 0 ms; [CKSEL=0010 SUT=00]
Int. RC Osc.; Start-up time: 6 CK + 4.1 ms; [CKSEL=0010 SUT=01]
Int. RC Osc.; Start-up time: 6 CK + 65 ms; [CKSEL=0010 SUT=10]
Ext. Low-Freq. Crystal; Start-up time: 32K CK + 0 ms; Int. Cap.; [CKSEL
Ext. Low-Freq. Crystal; Start-up time: 32K CK + 4.1 ms; Int. Cap.; [CKSE
Ext. Low-Freq. Crystal; Start-up time: 32K CK + 65 ms; Int. Cap.; [CKSEL
Auto Verify
Smart Warnings
Program
Verify
Read
Setting device parameters, serial programming mode ..OK
Entering programming mode.. OK
Programming fuses.. 0xFF, 0x99E2 .. OK
Leaving programming mode.. OK

As Figure 7 describes, the only fuses that should be programmed are:

- Brown-out Detection disabled
- JTAG Interface Enabled
- Serial Program downloading (SPI) enabled
- Boot Flash Section size = 1024 words
- Internal RC Oscillator; Start-up time 6CK + 65 ms

## ATmega169 Firmware

The firmware that realizes the temperature control application is written in IAR EWAVR 2.27b. The timing related functions are written for an ATmega169 running at 1 Mhz except the RTC clock and the LCD frame rate which is clocked from an external 32 kHz crystal. The crystal is mounted on the STK502 board.

### Interrupts Used

**LCD Start of Frame** In this interrupt the data from the LCD_displayData buffer is latched to the LCD Data Registers. The variable LCD_Blink toggles every time this interrupt occurs. The interrupt is dependent of the external 32 kHz crystal.

**Timer/Counter2 Overflow** This interrupt is used to increment the variable SECOND, which the whole RTC clock builds on. Timer/Counter2 is clocked asynchronous from the 32 kHz and is therefore independent of the clock frequency.

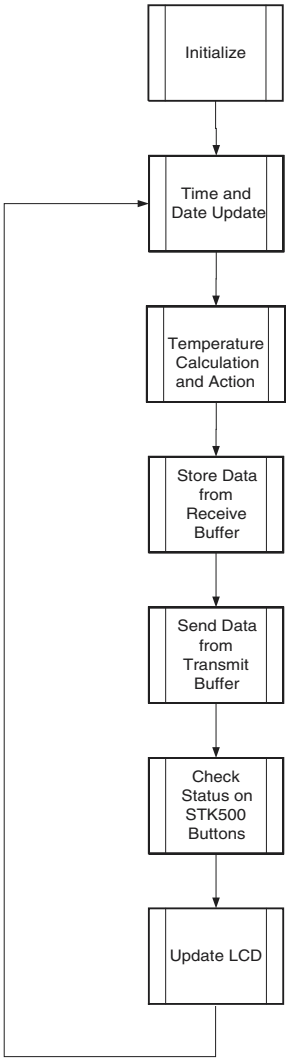
**USART0, RX Complete** This interrupt takes care of incoming data from the UART interface.

**USART0, Data Register Empty** This interrupt transmits data out through the UART interface.

## Main Loop

Figure 8 shows the main loop.

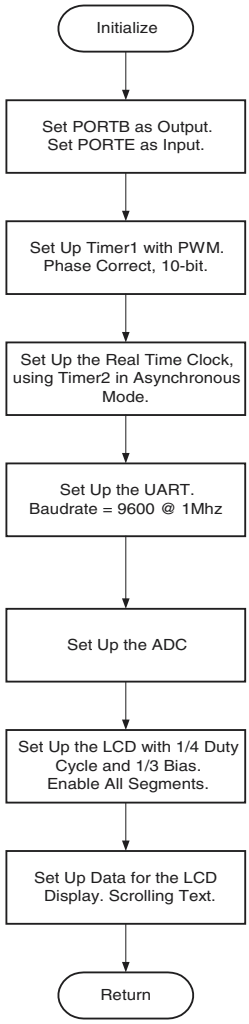
**Figure 8.** Main Loop



## Initialize

After a Reset the firmware will initialize the ATmega169 and its integrated peripherals. The initialization runs only one time after a Reset.

**Figure 9.** Initialize




PORTB is set as output and should be connected to the LEDS on STK500. PB5 (OC1A) and PB6 (OC1B) shows the offset between measured temperature and selected temperature set point. PB4 and PB7 are heating and cooling pins respectively. Connect a heating and cooling element to these pins.

DDRE is set as input and should be connected to the SWITCHES on the STK500. PE7, PE6, and PE5 are used to select what information should be displayed on the LCD and adjusting Time/Date, temperature set point and the LCD contrast.

Timer/Counter1 is set up with PWM to use on the OC1A/OC1B (PB5/PB6) pins.

Enable Timer/Counter2 with asynchronous operation, for the RTC. By using an external 32 kHz crystal the RTC can run independently of the ATmega169 system clock, and will also run during sleep.

Set up the UART with both RX and TX enable, baud rate 9600 @ 1 MHz, asynchronous operation, 8-bit character size, 1 stop bit and Disable Parity mode.

Set up the ADC in Single Ended mode. Differential mode can be selected by setting ADC_init(Differential) instead of ADC_init(SingleEnded) in the source code. Disable digital input on PORTF and run a dummy ADC conversion.

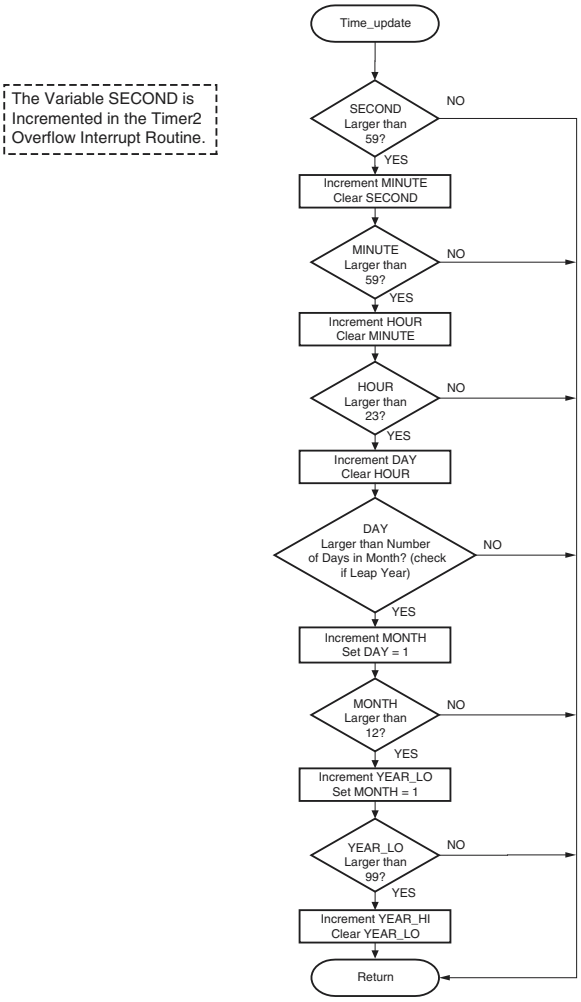
Enable all segment pins on the ATmega169. Select the 32 kHz as clock source for the LCD, and set the prescaler bits. Select 1/4 duty cycle and 1/3 bias. Set up Timer/Counter0 Compare Match interrupt to give the required delays for the scrolling and blinking speed of the information on the LCD display.

Start scrolling the initial string over the LCD display.

## Time and Date Update

This routine updates the clock and date according to the variable SECOND that gets incremented every second in the Timer/Counter2 Overflow interrupt routine. The whole update routine is self-explaining from the flow-chart.

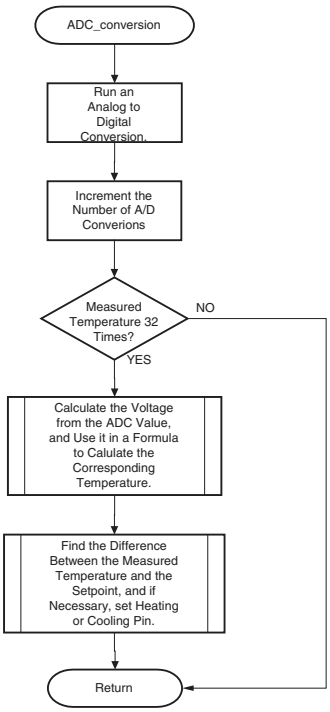
**Figure 10.** Time and Date Update



## Temperature Calculation

In this function the voltage over the NTC thermistor will be measured and the temperature calculated.

**Figure 11.** Temperature Calculation

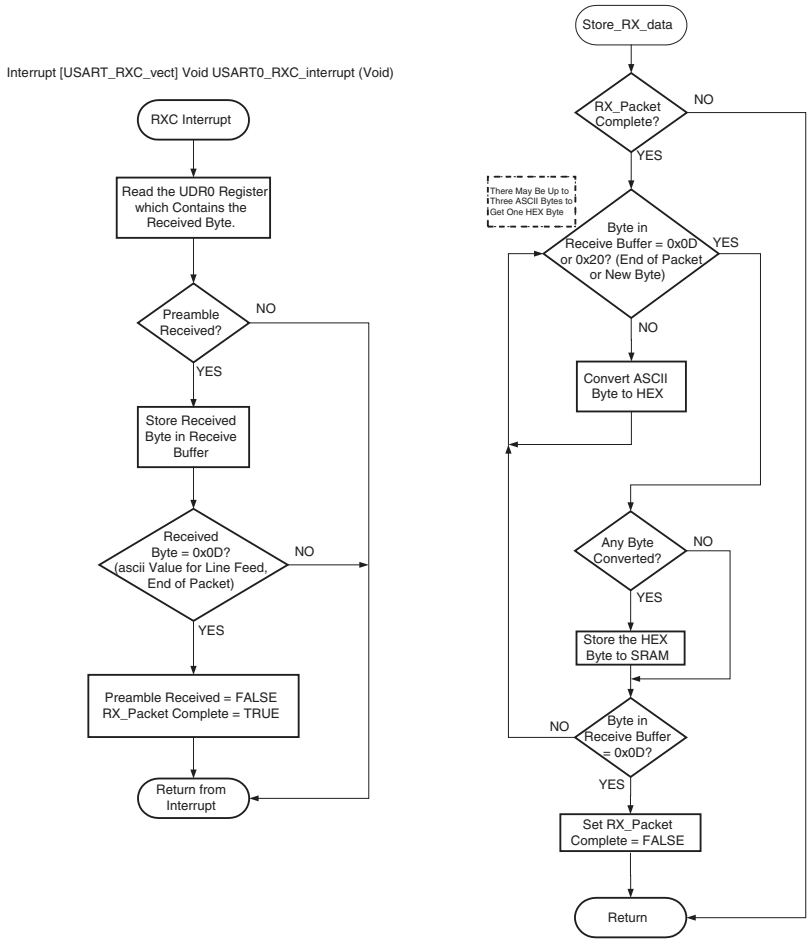

ADC_conversion
Run an Analog to Digital Conversion.
Increment the Number of A/D Converions
Measured Temperature 32 Times?
NO
YES
Calculate the Voltage from the ADC Value, and Use it in a Formula to Calulate the Corresponding Temperature.
Find the Difference Between the Measured Temperature and the Setpoint, and if Necessary, set Heating or Cooling Pin.
Return

Start by doing an A/D conversion. The average of 32 ADC results is used in a formula to calculate the corresponding temperature. The heating or cooling pin are set depending on the difference between the calculated temperature and the temperature set point. The temperature set point is selected by the user. The bigger the difference is, the brighter the heating or cooling LED will shine.

## Receive Data from PC

These routines take care of data coming from the PC through the UART interface.

**Figure 12.** Receive Packet from PC




### USART_RXC_interrupt

Receiving data from the PC is done in the USART_RXC_interrupt routine. It will discard all data until the correct preamble bytes are received. Then it will store the succeeding bytes in a receive buffer until the byte for Line Feed appears (ASCII value: 0x0D) This indicates the end of the packet and RX_Packet_complete Flag will be set to TRUE.

**Store_Rx_data**

The packet is then converted from ASCII to hexadecimal. One HEX-byte can contain 1 - 3 ASCII bytes. ASCII-bytes that belong to different HEX-bytes are separated by an ASCII-space (0x20). The converted HEX-bytes get continuously stored in the correct place in SRAM until the Line-Feed byte appears, which is the end of the packet.

**Table 1.** Receive Packet from PC

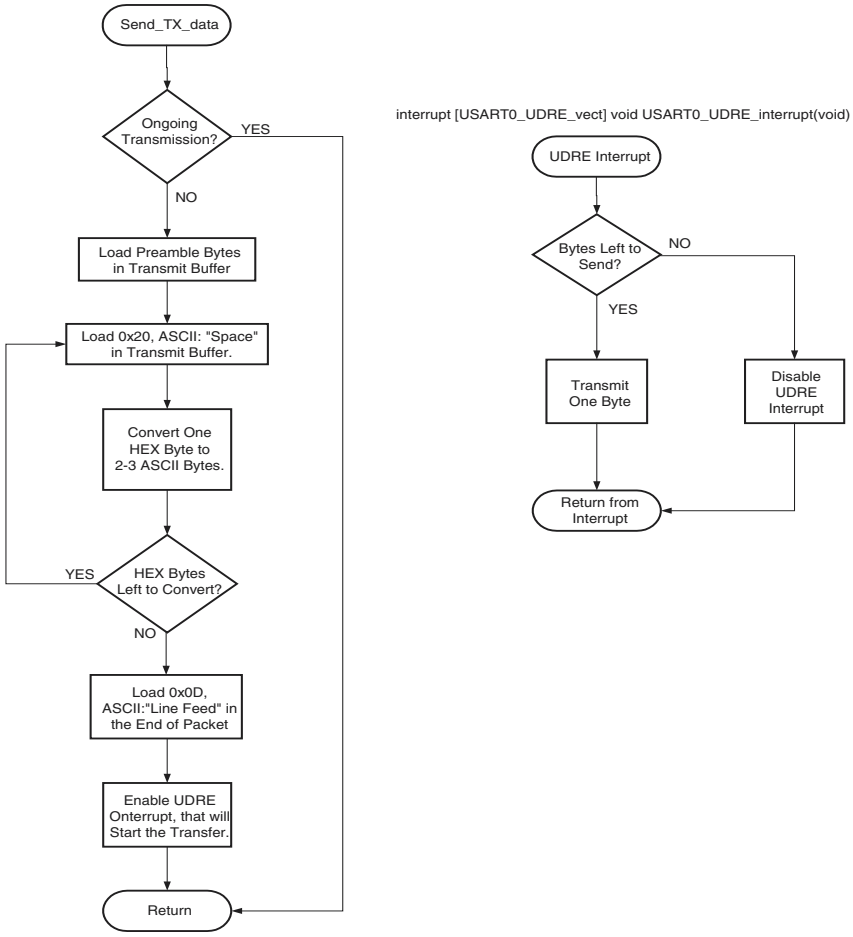
| | |
|---|---|
| Preamble “STK502” | 6 byte |
| ASCII-space (0x20) | 1 byte |
| HOUR | 2 byte |
| ASCII-space (0x20) | 1 byte |
| MINUTE | 2 byte |
| ASCII-space (0x20) | 1 byte |
| SECOND | 2 byte |
| ASCII-space (0x20) | 1 byte |
| DATE | 2 byte |
| ASCII-space (0x20) | 1 byte |
| MONTH | 2 byte |
| ASCII-space (0x20) | 1 byte |
| YEAR_HI | 2 byte |
| ASCII-space (0x20) | 1 byte |
| YEAR_LO | 2 byte |
| ASCII-space (0x20) | 1 byte |
| SET_POINT | 2 byte |
| ASCII-carriage return (0x0D) | 2 byte |
| ASCII-line feed (0x0A) | 2 byte |

Transferring the data in ASCII allows a standard terminal to be used on the PC.

## Transmit Packet to PC

These routines transmit the data from ATmega169 to the PC.

**Figure 13.** Transmit Packet to PC



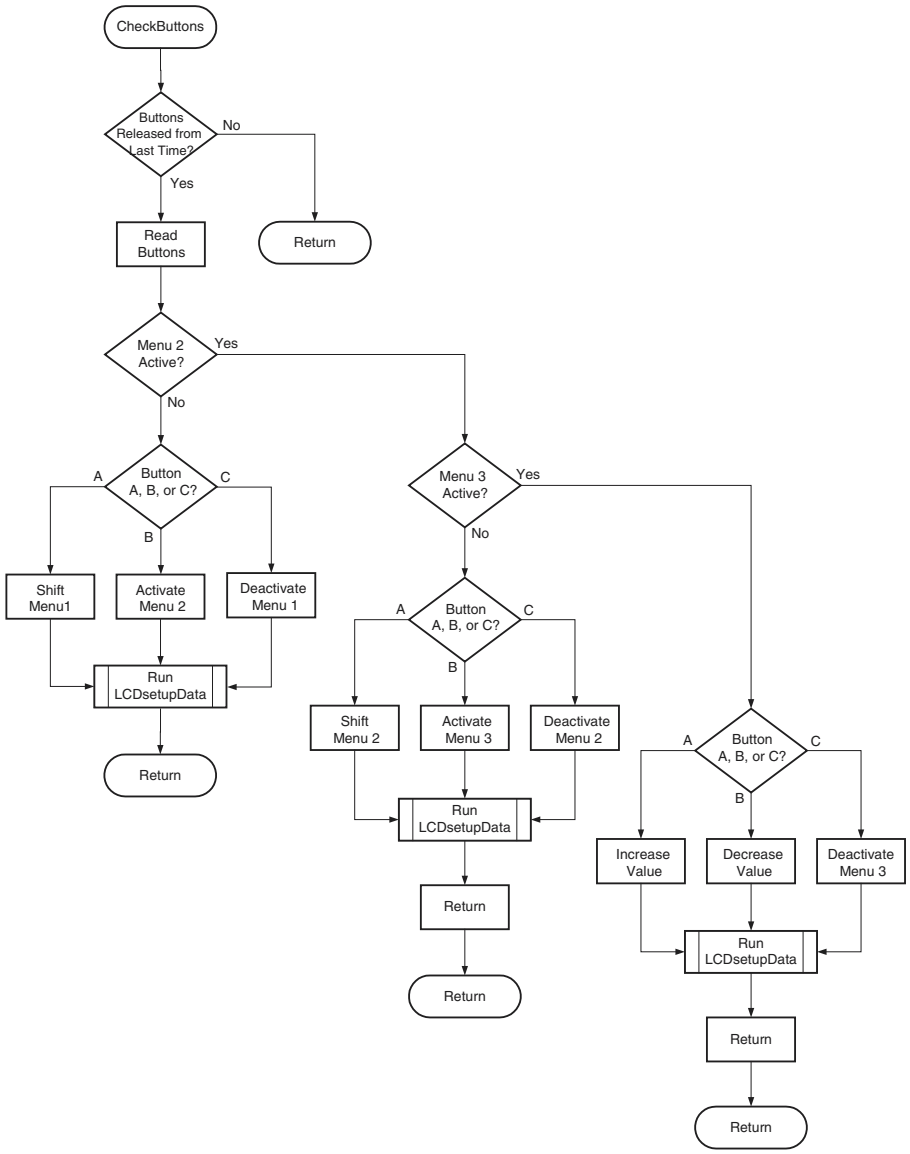

A transmit packet starts with the preamble bytes, and then the HEX-bytes that are to be transmitted get converted to ASCII-bytes and loaded in the packet. Between each HEX-byte that gets converted, an ASCII-byte for space (0x20) is inserted. At the end of the packet, an ASCII-byte for Line Feed is added to indicate the end of frame. The transmission starts by enabling the UDRE interrupt. When all bytes are transmitted the UDRE interrupt gets disabled.

**Table 2.** Transmit Packet to PC

| | |
|---|---|
| Preamble “STK502” | 6 byte |
| ASCII-space (0x20) | 1 byte |
| HOUR | 2 byte |
| ASCII-space (0x20) | 1 byte |
| MINUTE | 2 byte |
| ASCII-space (0x20) | 1 byte |
| SECOND | 2 byte |
| ASCII-space (0x20) | 1 byte |
| DATE | 2 byte |
| ASCII-space (0x20) | 1 byte |
| MONTH | 2 byte |
| ASCII-space (0x20) | 1 byte |
| YEAR_HI | 2 byte |
| ASCII-space (0x20) | 1 byte |
| YEAR_LO | 2 byte |
| ASCII-space (0x20) | 1 byte |
| SET_POINT | 2 byte |
| ASCII-space (0x20) | 1 byte |
| TEMP_HIGHBYTE | 2 byte |
| ASCII-space (0x20) | 1 byte |
| TEMP_LOWBYTE | 2 byte |
| ASCII-space (0x20) | 1 byte |
| OFFSET | 2 byte |
| ASCII-space (0x20) | 1 byte |
| Firmware revision | 2 byte |
| ASCII-carriage return (0x0D) | 2 byte |
| ASCII-line feed (0x0A) | 2 byte |

## STK500 Switches

**Figure 14.** CheckButtons




There are three switches that are used as inputs to the application. To do several tasks with only three switches, a menu system is needed. Figure 14 shows three menus in a hierarchy, which are used in this code. See Figure 2 for the a overview of the menus.

Figure 14 refers to ButtonA/B/C, in the application these buttons can be found at:

“ButtonA” is SW7 which is connected to PE7.

“ButtonB” is SW6 which is connected to PE6.

“ButtonC” is SW5 which is connected to PE5.

Example:

After a RESET the LCD is set up to scroll a text. None of the three menus are active. Pressing the SW7 will toggle between the alternatives in Menu 1 (Clock, Date, Set point, Temperature, Offset, and Contrast)

To adjust the variable MINUTE: Press SW7 until “CLOCK” appears in the LCD display, and select this by pressing SW6 to activate Menu 2 under “CLOCK”. Pressing SW7 will now toggle between the alternatives in Menu 2, Hour, Minute, and Second. Press SW7 until the variable MINUTE is blinking in the LCD display, and select this by pressing SW6. Now Menu 3 is activated and the colons should disappear. Pressing SW7 will increase the variable MINUTE and SW6 will decrease. When desired value has been selected, press SW5 to deactivate Menu 3, and go back to Menu 2. Press SW5 once more to deactivate Menu 2 and go back to Menu 1.

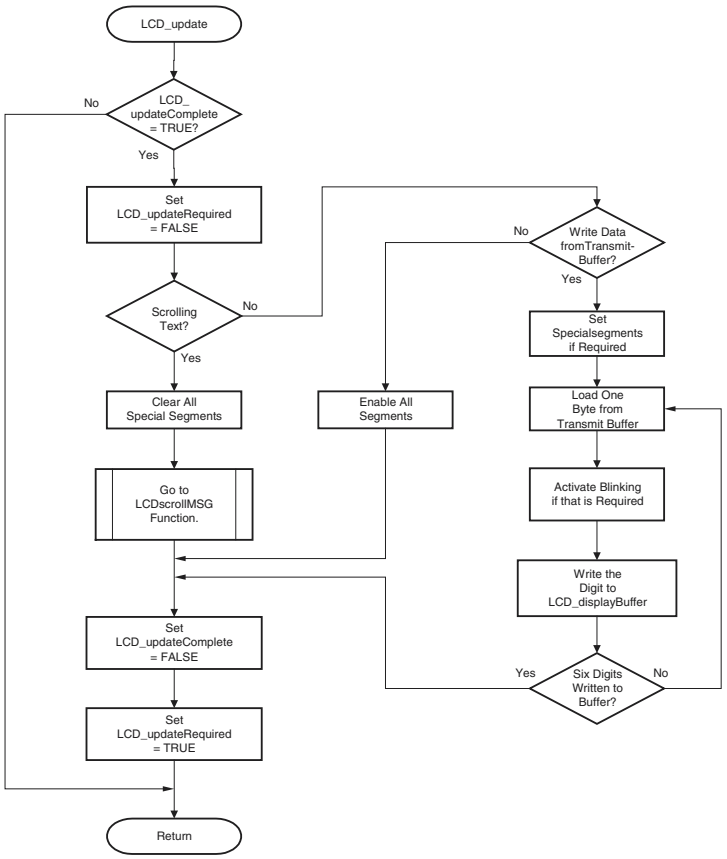
The same procedure can be used to adjust the other variables as well.

## LCD

Writing to the LCD requires an LCD driver. The driver used in this application is described in the application note “AVR065: LCD Driver for the STK502 LCD”.

### LCD Update

**Figure 15.** LCD_update




This function will load data into the LCD_displayBuffer.

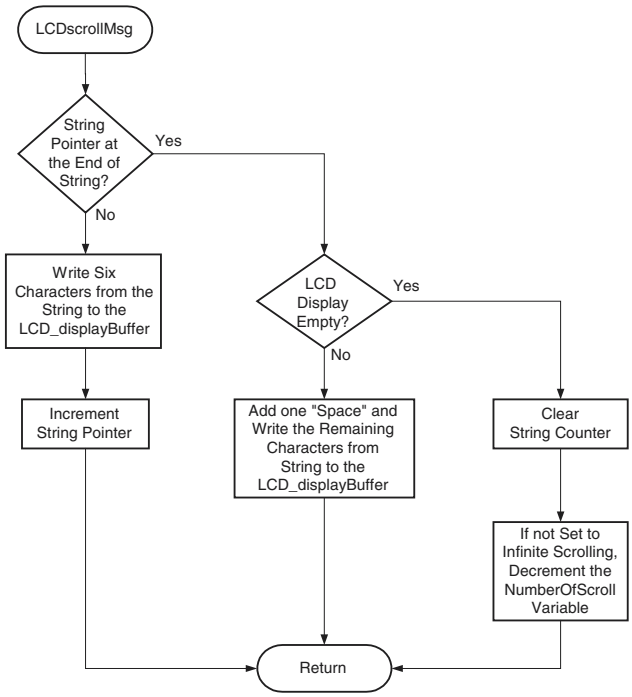
First check if the LCD has been updated with the data already in the LCD_displayBuffer. If so, set the LCD_update required to FALSE. This will prevent the LCD to be updated with incomplete data, if an LCD Start of Frame interrupt should occur during this function.

If a text-string is to be scrolled, clear display and call the LCDscrollMSG function. If no text to scroll, check if there is data to write from the TransmitBuffer, and load the data into the LCD_displayBuffer. Digits can be set to blink on the display. To do this the digit will be loaded with either its data value or a ASCII-space (0x20), depending on the variable LCD_Blink.

After the LCD_displayBuffer has been updated, the LCD_updatedComplete will be set to FALSE, and LCD_updateRequired to TRUE. This will cause the LCD_displayBuffer to be written to the LCD in the LCD Start of Frame interrupt.

## Scroll Function

**Figure 16.** LCDscrollMsg

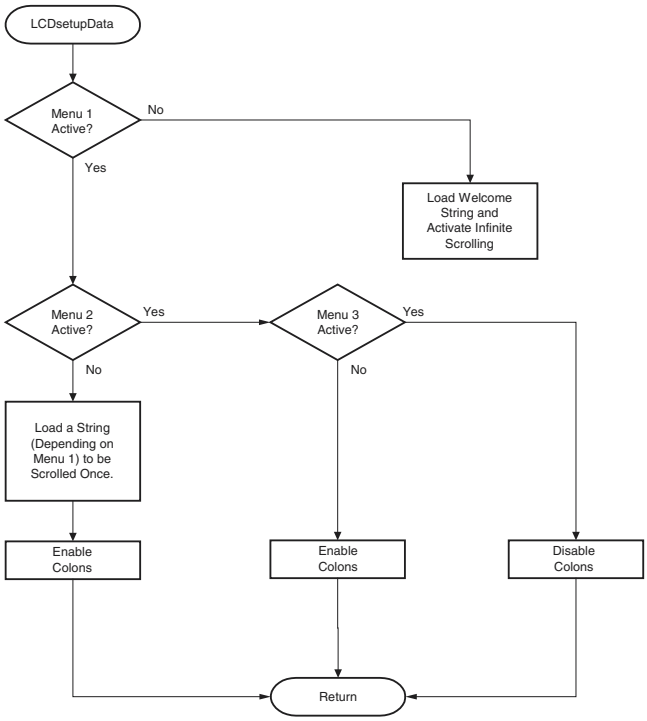

LCDscrollMsg
String Pointer at the End of String?
Yes
No
Write Six Characters from the String to the LCD_displayBuffer
LCD Display Empty?
Yes
No
Increment String Pointer
Add one "Space" and Write the Remaining Characters from String to the LCD_displayBuffer
Clear String Counter
If not Set to Infinite Scrolling, Decrement the NumberOfScroll Variable
Return

This function shifts the six digits on the LCD one step to the left. An external delay or interrupt is needed in order to get the right speed of the scrolling text. The scroll function uses a pointer to keep track of what characters to shift in and out of the LCD. When all the six digits have been updated, the pointer gets incremented by one in order to shift the text-string one step the next time this function is called.

If the pointer has reached the end of the string, the LCD has to be filled up with one ASCII-space at the time until all of the six digits are blank. This will “fade” out the text string.

## LCD Set-up Data

**Figure 17.** LCDsetupData

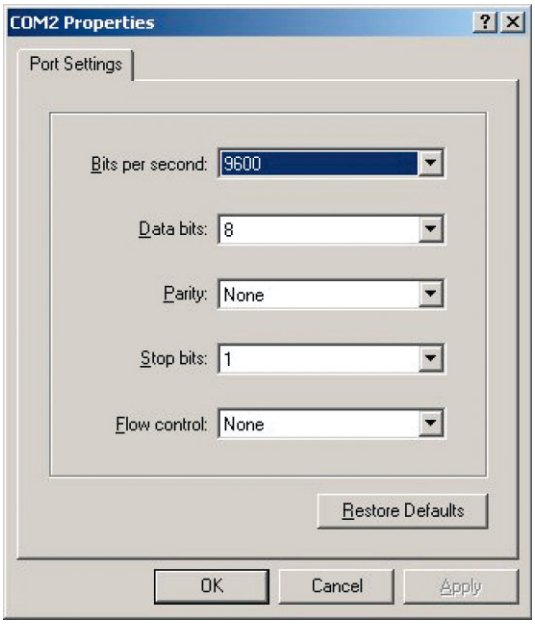



If Menu 1 isn't active the welcome string will scroll over the LCD. If Menu 1 is active but not Menu 2, the corresponding string will be scrolled once over the LCD and then the data belonging. If Menu 2 is active but not Menu 3, just enable the colons. And if Menu 3 is active, disable the colons to indicate that the current variable can now be adjusted.

## Terminal

All temperature and time information is transmitted through the UART-interface. A program on a PC can receive this data by connecting a serial cable between the “RS-232 SPARE” on the STK500 and a comport on the PC. A standard terminal can be used, e.g, HyperTerminal. Set up the terminal as shown in Figure 18.

**Figure 18.** Port Settings

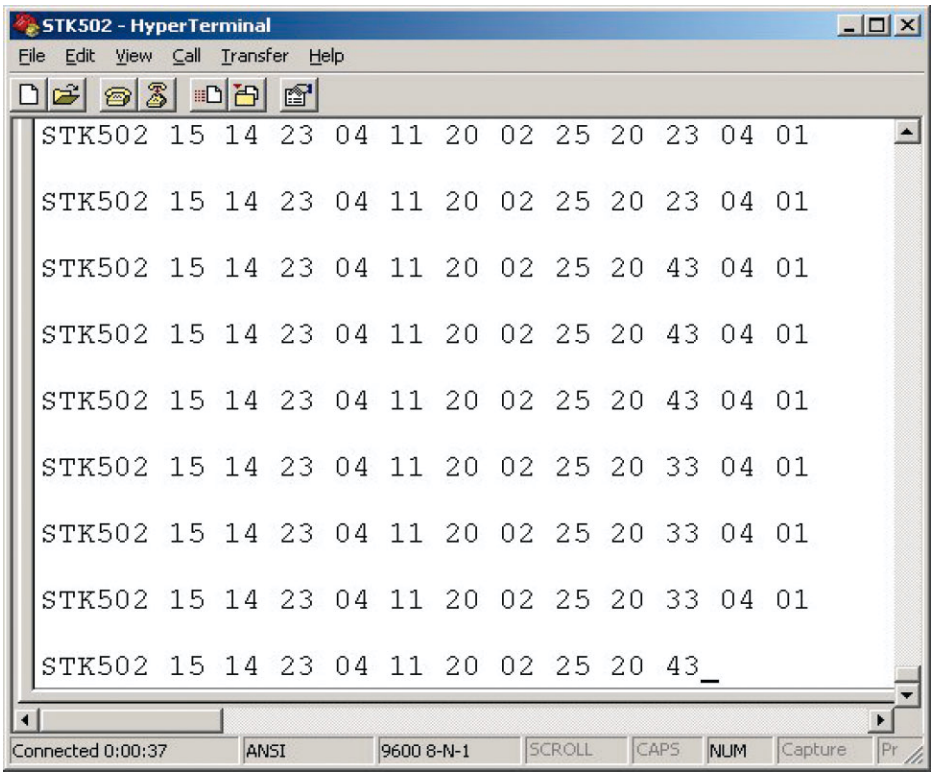



Press the connect button and the data from the ATmega169 should appear as in Figure 19. The data is presented according to Table 1.

**Table 3.** Transmit Packet from ATmega169 according to Figure 19

| | |
|---|---|
| Preamble | STK502 |
| Hour | 15 |
| Minute | 14 |
| Second | 23 |
| Day | 04 |
| Month | 11 |
| Yearhigh | 20 |
| Yearlow | 02 |
| Set point | 25 |
| °C high byte | 20 |
| °Clow byte | 23 |
| Offset | 04 |
| Versions number | 01 |

**Figure 19.** HyperTerminal




One can also adjust the variables within the ATmega169 from the terminal. This has to be done according to Table 1. For example, write: “STK502 14 37 02 25 11 20 02 24” in the terminal, and press enter to indicate end of frame. This will adjust the clock to 14h37m02s, the date will be November 25, 2002. And the temperature set point will be 24°C.

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